Investigation of the middle-to-upper crustal structural framework for the Wabash Valley Seismic Zone from high-quality seismic reflection profiles

USGS Award No.: 1434-HQ-97-GR-03194

J. H. McBride, D. R. Kolata, and W. J. Nelson
Illinois State Geological Survey
University of Illinois at Urbana-Champaign
615 East Peabody Drive
Champaign IL 61820

Tel: 217-333 5107
Fax: 217-333 2830
E-mail: mcbride@seismic.isgs.uiuc.edu
URL: http://www.isgs.uiuc.edu/

**Program Element**: III. Understanding Earthquake Processes

**Key Words**: Tectonic Structures; Seismotectonics; Reflection Seismology; Source characteristics.

**Investigations undertaken**

The Illinois State Geological Survey has been pursuing a successful program of acquiring previously surveyed seismic reflection profiles from the oil industry in order to study structures within the Precambrian crystalline basement and their possible relation to overlying Phanerozoic structure. These data have also provided constraints on understanding the seismogenic source beneath parts of the Illinois Basin, especially the "Wabash Valley seismic zone" (WVSZ) (e.g., *McBride et al*., 1997). To date we have obtained thousands of kilometers of seismic data originally acquired by Marathon, Mobil, Amoco, Seismic Exchange Inc. (e.g., Fig. 1), Seismic Specialists, Inc., and others Several of these profiles lie within the region of the WVSZ (Fig. 2). In order to supplement this program, we have now purchased the license to parts of two strategically located, long-record seismic reflection profiles which cover a specific area where major deep basement structures have been verified (*McBride et al.*, 1997). These two profiles, when combined with seismic data exclusively licensed to the Illinois State Geological Survey (ISGS), are for the first time providing a structural framework for the WVSZ in the middle-to-upper crust, which has hosted several moderate-magnitude earthquakes (Fig. 2). *Potter et al.* (1995) have given a description of the data set of which these two profiles are a part.

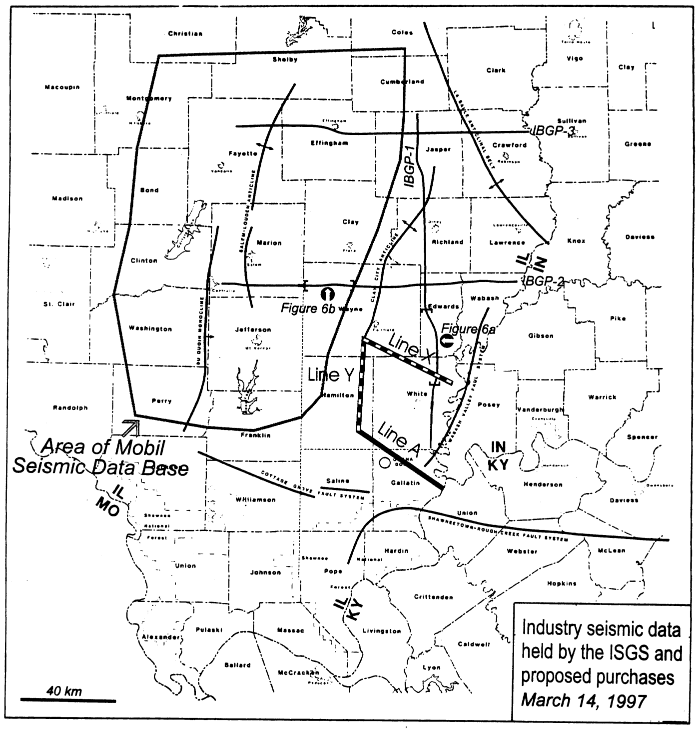


**Figure 1.** Location map of seismic reflection profiles currently licensed and recently purchased (lines X and Y (dashed lines)). Licensed seismic data include the IBGP-1, 2, and 3 series (thin solid lines), the Mobil Data Base (mainly within enclosed area), and Line A. Selected generalized regional geologic features shown.

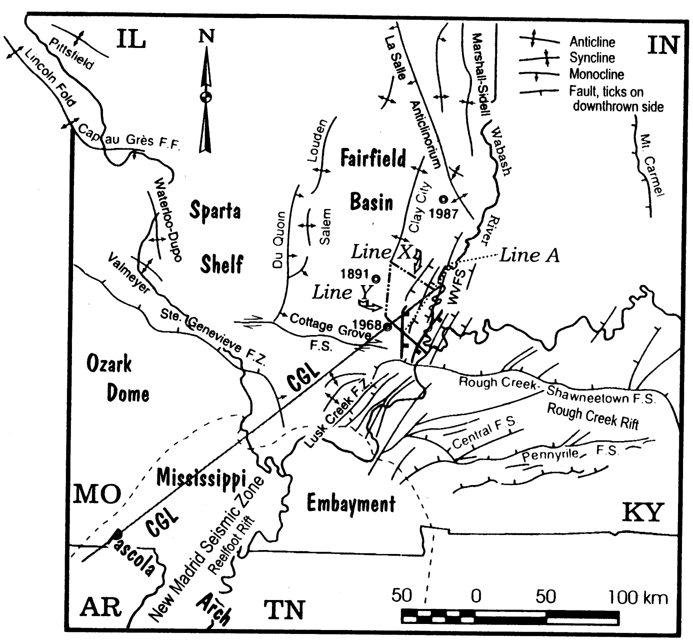


**Figure 2.** General location map of central U. S. Midcontinent showing prominent faults, structural axes, and structural lineaments. Also shown is the location of the seismic reflection profiles for proposed purchase (Lines X and Y, dashed lines), the profile previously licensed (Line A, solid line) and the epicenters of the

November 9, 1968, the June 10, 1987, and the September 27, 1891, earthquakes. The location of the Commerce Geophysical Lineament (CGL) is simplified from *Langenheim and Hildenbrand* (1997). WVFS is Wabash Valley Fault System. F. F. is faulted flexure; F. S. is fault system; F. Z. is fault zone.

## Results

We have been in prolonged negotiations with the data owners over details of the price and content of the purchase of these data. Part of the reason for the delay is the sensitive nature of these data, which are primarily used for oil exploration and production. The delay has pushed back considerably our progress on accomplishing the aims of the project; however, we have received the data now in paper form. We are currently negotiating the purchase of the tapes in order to pursue reprocessing of the data. Once the tapes are received, we will reprocess the records in order to extend the total travel time from 5 to 8 s (or from ~15 km to ~25 km, equivalent), which will then encompass the depths of the deepest earthquakes in the WVSZ. Having now identified a dipping reflector sequence for the 1968 reverse fault event on Line A (Fig. 1) (*McBride et al*., 1997), it now will be possible to trace this sequence through the study area as well as to search for similar, possibly seismogenic dipping reflector sequences. The study area has had several moderate magnitude events and is thought to be deforming in a consistent manner involving a dextral NE-directed strike-slip and reverse fault regime (*Langer and Bollinger*, 1991) under an ENE maximum horizontal stress field (*Ellis*, 1994).

In February 1998, Christopher Potter (USGS, Denver) and John McBride re-examined all of Lines X and Y in consultation with their owners, Paul Schillmoller and Pasquale Scaturro in Denver. Both lines show spectacular series of basement reflector structures, which in places extend down to and are cut off by the bottom of the 5-s display. Line X is approximately parallel to Line A and shows a prominent sequence of dipping reflectors that begins at the base of the Paleozoic section beneath the WVFS and continues to the bottom of the 5-s display. This dipping sequence is more pronounced than that observed on Line A, but is likely correlative. The dipping sequence continues westward at least as far as the tie with Line Y and appears to be cut in places by the normal faults of the Wabash Valley Fault System. The north-south Line Y shows a dipping reflector sequence in the basement with a strong north-inclined component (Fig. 3). Individual dipping reflectors continue from the crystalline basement into the lowermost Paleozoic section where they disrupt the prominent basin-wide base of the Cambrian Knox Formation reflector. Both lines tie with deep basement-penetrating wells (Cuppy No. 1 and Cisne No. 1; *Potter et al*., 1997).

A significant new observation from Lines X and Y is the occurrence of basement dipping reflectors that truncate and offset horizontal stratal reflectors within the basement and that continue up to and disrupt lower Paleozoic sedimentary strata. Significantly, these dipping sequences in places disrupt lower Paleozoic strata in a thrust sense, implying tectonic reactivation of basement structure. The vertical depth extent of the dipping basement reflectors is at least 10 km, indicating major structures in the upper and middle crust. The relevant portions of Lines X and Y tie to Line A as well as to Line IBGP-1 (Fig. 2), previously released to the ISGS. All together, these lines plus the others donated to the ISGS, will allow us to correlate the subhorizontal and dipping sequence on Line A, associated with the 1968 event, over a much larger area, as well as to better establish the basement reflector structural framework beneath the WVSZ. An interpretation of Seismic Exchange Inc. Lines IBGP-1 and IBGP-2 reveals a portion of this structural framework along E-W and N-S profiles. Disruptions of the Precambrian basement surface and of lower Paleozoic horizons appear on N-S Line IBGP-1 and E-W Line IBGP-2 that are associated with dipping basement reflectors, similar to those viewed on Lines X and Y. The intensity of disruption increases southward toward the Wabash Valley Fault System (Fig. 2).

Our ongoing regional mapping of reflector sequences in this region has continued to improve our knowledge of the deep structural framework of the WVSZ. On the northern boundary of the study area, highly coherent basement reflectivity is expressed as a synformal “wedge” of dipping and sub-horizontal reflections situated beneath the center of the Illinois Basin that thickens and deepens to the northeast (e.g., 0 to ~5.3 km thickness along a 123-km south-to-north line, S-1) (Figs. 3 and 4). The boundaries of this sequence are usually marked by distinct steeply dipping reflections (interpreted as thrust faults) that continue or project up to antiformal disruptions of lower Paleozoic marker reflectors (e.g., base of Cambrian-

Ordovician Knox Group) implying middle Paleozoic or later tectonic reactivation of Precambrian basement structure (Fig. 4). Further, the sub-sequence boundaries and deeper dipping reflectors are spatially associated closely with the epicenters of two of the largest 20th-century earthquakes in the central USA Midcontinent (1987.06.10 $m_{bLg}$=5.2 and 1974.04.03 $m_{bLg}$=4.7) (Fig. 4)). Both of these events have derived hypocenters within the upper 15 km of the crust with approximately east-west compression focal mechanism solutions. The areal extent of the sub-sequence also appears to generally correspond to an anomalous concentration of larger magnitude events. Our planned reprocessing of Lines X and Y will augment and extend not only the depth of investigation of these data (Fig. 4), but also the regional extent.

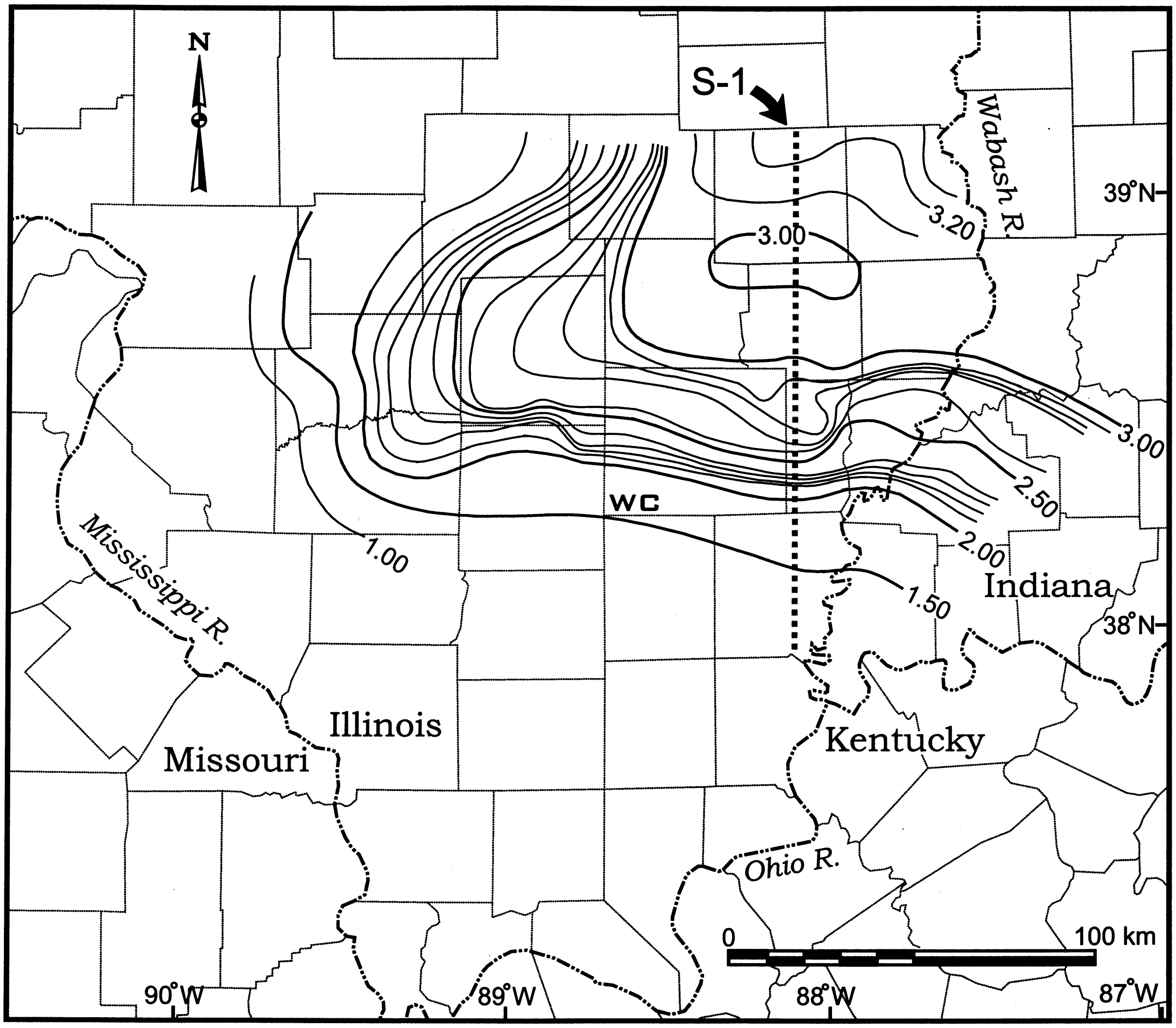


**Figure 3.** Two-way isotraveltime to base of Proterozoic Centralia sequence as mapped in part from seismic lines shown in Figure 1 (IBGP's) (*McBride and Kolata*, 1998). Since the lateral change in seismic velocity for the Paleozoic section across the Illinois Basin and the vertical change in velocity between the Paleozoic section and Precambrian basement are relatively small, little appreciable traveltime distortion of depth relations is expected. Contour interval is 100 ms (or 300 m at 6.0 km s$^{-1}$). For traveltime less than 2 s, contour interval is 500 ms. S-1 is IBGP-1 (Fig. 1).

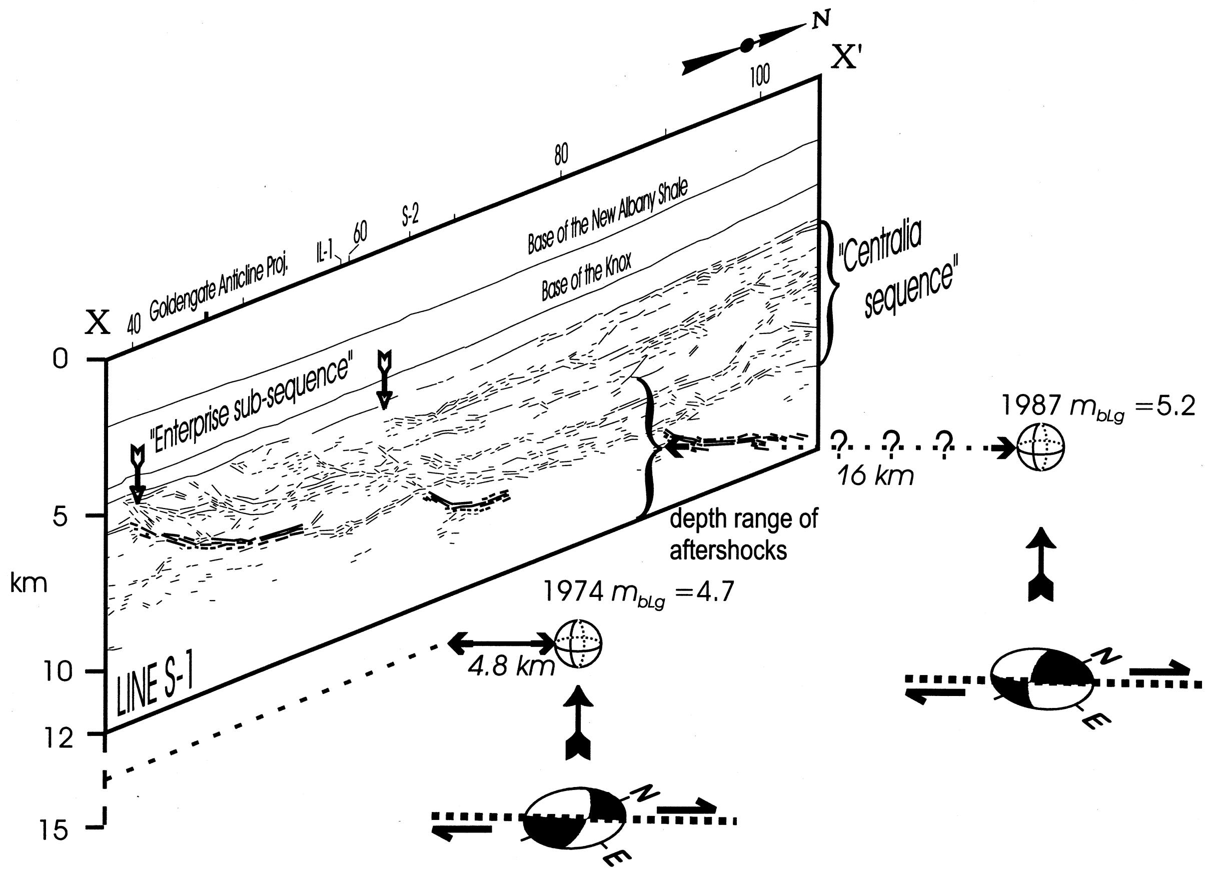


**Figure 4.** Perspective diagram of a portion of Line S-1 (Fig. 3) with area of anomalous "Enterprise sub-sequence" within the Centralia sequence noted (*McBride and Kolata*, 1998). Prominent dipping reflections are shown in bold. Relative location of hypocenters of the 1974 and 1987 earthquakes are shown with focal mechanism solutions indicating interpreted (see *Langer and Bollinger*, 1991) northeast-striking strike-slip faulting (from *Herrmann*, 1979; *Taylor et al.*, 1989).

## REFERENCES CITED


Ellis, W. L., 1994, Summary and discussion of crustal stress data in the region of the New Madrid seismic zone, in *Investigations of the New Madrid Seismic Zone*, Shedlock, K. M. and Johnston, A. C., eds., *U. S. Geol. Surv. Prof. Pap. 1538-B*, 1-13.

Herrmann, R. B., 1979, Surface wave focal mechanisms for eastern North America earthquakes with tectonic implications, Journal of Geophysical Research B, v. 84, p. 3543-3552.

Langenheim, V. E. and Hildenbrand, T.G., 1997, Commerce geophysical lineament; its source, geometry, and relation to the Reelfoot Rift and New Madrid seismic zone, Geological Society of America Bulletin, 109, p. 580-595.

Langer, C. J. and Bollinger, G. A., 1991, The southeastern Illinois earthquake of 10 June 1987: the later aftershocks: Bulletin of the Seismological Society of America, v. 81, p. 423-445.

McBride, J. H., Sargent, M. L., and Potter, C. J., 1997, Investigating possible earthquake-related structure beneath the southern Illinois Basin from seismic reflection: Seismological Research Letters, v. 68, p. 641-649.

McBride, J. H. and Kolata, D. R., 1998, The upper crust beneath the central Illinois Basin, USA. Geological Society of America Bulletin 110, in press.

Potter, C. J., Drahovzal, J. A., Sargent, M. L., and McBride, J. H., 1997, Proterozoic structure, Cambrian rifting, and younger faulting as revealed by a regional seismic reflection network in the southern Illinois basin: Seismological Research Letters, v. 68, p 537-552.

Taylor, K. B., Herrmann, R. B., Hamburger, M. W., Pavlis, G. L., Johnston, A., Langer, C., and Lam, C., 1989, The southeastern Illinois earthquake of 10 June 1987: Seismological Research Letters, v. 60, p. 101-110.

## Non-technical Summary

After prolonged negotiations with the owners of seismic reflection profiles located near some of the major epicenters of the Wabash Valley Seismic Zone, we have secured a license to the data; negotiations for purchasing the tapes should be concluded before the end of 1998. Ongoing collection, interpretation, and mapping of seismic reflection data in the Wabash Valley Seismic Zone have documented possibly seismogenic structure. The planned analysis of the new data will extend this work further to the south in Illinois and deeper into the subsurface.

## Reports published

None

No seismic data are publicly available.